168208

Review and Analysis of Data On Tire Failure Rate During Endurance Tests
Submittal to Docket No. NHTSA-00-8011 -39

Nancy Bell NEB 41 29 102
Attorney Advisor

US DOT Docket Management System

Please place the attached endurance testing data and analysis in the aforementioned docket.

Attachment

Review and Analysis of Data

on

Tire Failure Rate During Endurance Tests

Date: Friday, April 26, 2002

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act of 2000 mandates a rulemaking proceeding to revise and update our safety performance requirements for tires. In response to this mandate, NHTSA initiated a tire-testing program including a series of endurance tests. The goal of these tests is to establish the endurance test parameters. One part of this program is a series of endurance tests similar to the test procedure in S5.4 of standard FMVSS No. 109. These tests establish the endurance (time-to-failure) with respect to percent rated speed, percent maximum load specified on the sidewall (SW) and inflation pressure. The Rubber Manufactures Association (RMA) has also provided test results from endurance tests they have completed. This study analyzes the results of these endurance tests. The primary measure used in this analysis is the time-to-failure.

Based on the available data and analysis it appears that the following percentages of tires will not complete the proposed endurance tests: about 30 % of tires with a speed rating of Q and R, about 25 % of S and T, about 9 % of U and about 3 % of H.

INTRODUCTION

The Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act of 2000 mandates a rulemaking proceeding to revise and update our safety performance requirements for tires. In response to this mandate, NHTSA initiated a tire-testing program including a series of endurance tests. The goal of these tests is to establish the endurance test parameters. One part of this program is a series of endurance tests similar to the test procedure for S5.4 in standard FMVSS No.109. These tests establish the endurance (time-to-failure) with respect to percent rated speed, percent maximum load specified on the sidewall (SW) and inflation pressure. The Rubber Manufactures Association (RMA) has also provided test results from endurance tests they have completed. This study analyzes the results of these endurance tests. The primary measure used in this analysis is the time-to-failure.

NHTSA TESTS

NHTSA conducted two sets of tests:

First set of tests were conducted on 3 selected types of tires:

(I) P225/60R16 with load index of 97 (730 kg / lbs) and speed rating[1] of H (210 km/h / 130 mph)

(II) P205/65R15 with load index of 92 (630 kg / lbs) and speed rating of T (190 km/h / 118 mph)

(III) P235/75R15 with load index of 105 (925 kg / lbs) and speed rating of S (180 km/h / 112 mph)

Ten tires each of type I and type II were tested at constant speeds of 100 and 120 km/h, while 20 tires of type III were tested. Table 1 is a test matrix of first set of endurance tests conducted by NHTSA. All tires were tested at 180 kPa (26 psi)

[1] The speed rating of a tire indicates the speed category (or range of speeds) at which the tire can carry a load under specified service conditions. The speed rating system used today was developed in Europe in response to the need to control the safe performance of tires at standardized speeds. A letter from A to Z symbolizes a tire's certified speed rating, ranging from 5 km/h (3 mph) to above 300 km/h (186 mph). This rating system describes the top speed for which a tire is certified. It does not indicate the total performance capability of a tire.

Table 1: Test Matrix of Endurance Tests Conducted by NHTSA: Set 1

Tire Type (LI) SR	Percent SW Load Duration	Test Speed Km/h (mph)	Number of Tires Tested
P225/60R16 (97) H Type I	100 % SW load for first 8 hours 115 % SW load for next 10 hours 125 % SW load for next 32 hours	100 (62)	10
		120 (75)	10
	100 % SW load for first 8 hours 110 % SW load for next 10 hours 115 % SW load for next 32 hours	120 (75)	10
P205/65R15 (92) T Type II	100 % SW load for first 8 hours 115 % SW load for next 10 hours 125 % SW load for next 32 hours	100 (62)	10
		120 (75)	10
	100 % SW load for first 8 hours 110 % SW load for next 10 hours 115 % SW load for next 32 hours	120 (75)	10
P235/75R15 (105) S Type III	100 % SW load for first 8 hours 115 % SW load for next 10 hours 125 % SW load for next 32 hours	100 (62)	20
		120 (75)	20
	100 % SW load for first 8 hours 110 % SW load for next 10 hours 115 % SW load for next 32 hours	120 (75)	20

Table 2: Test Matrix of Endurance Tests Conducted by NHTSA: Set 2

Test Speed	Tire type (LI) (SR)	Number of tires tested	Pressure kPa (psi)	Percent SW Load Duration
140 km/h (87 mph)	P205/65R15 (92) H	2	160 (23)	100 % SW load for first 8 hours 115 % SW load for next 10 hours 125 % SW load for next 32 hours
		2	200 (29)	
	P205/60R15 (90) H	1	160 (23)	
		1	200 (29)	
	205/65R15 (94) H	1	160 (23)	
		1	200 (29)	
	P205/70R14 (93) T	1	160 (23)	
		1	200 (29)	
	P205/75R14 (95) S	1	160 (23)	
		1	200 (29)	
	P255/70R16 (109) S	1	160 (23)	
		1	200 (29)	
	P225/60R16 (97) S	1	160 (23)	
		1	200 (29)	
	P235/75R15 (105) S	1	160 (23)	
		1	200 (29)	

The second set of test were conducted on S, T and H speed rated tires each having 4, 1, and 3 levels of load index (LI) respectively. All tires were tested at 160 and 200 kPa pressure. Only H tires with 92 LI were tested twice at each pressure step, while other tests did not have repetitions. All the tires in this test were subjected to 140km/h test speed. Table 2 is a test matrix of second set of endurance tests conducted by NHTSA.

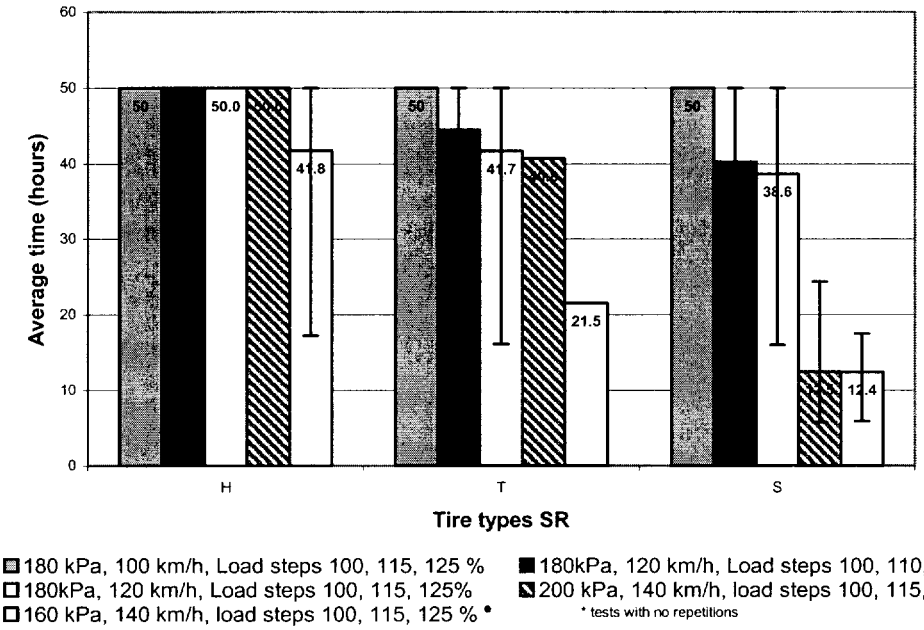
The tests were stopped either when the tire failed or when the test duration exceeded 50 hours. At this point the percent SW load and time were recorded.

NHTSA TEST RESULTS

Results for first test set:

The first three bars on left of Figure 1 shows that each and every tire of the type I, i.e. tires with speed rating H (210 km/h), completed the test duration of 50 hours without failure. The bars in Figure 1 show the maximum and minimum time-to-failure, or completion, for each test condition.

Figure 1: Comparison of time at failure of S, T, and H tires; NHTSA data



For type II (left three bars for T tire), i.e. T (SR =190 km/h) type tires, all the tires tested at test conditions speed = 100 km/h, load steps of 100, 115 and 125 % of the SW load, completed the test without failure. At test conditions speed = 120 km/h, load steps

of 100, 110 and 115 % of the SW load, and speed = 120 km/h, load steps of 100, 115 and 125 % of the SW load, 3 and 4 out of 10 tires tested at each condition, respectively, fail before the test completion criteria of 50 hours.

Similarly for type III (left three bars for T tire), i.e. S (SR = 180 km/h) type tires, all the tires tested at test condition speed = 100 km/h, load steps of 100, 115 and 125 % of the SW load, completed the test without failure. At test conditions speed = 120 km/h, load steps of 100, 110 and 115 % of the SW load, and speed = 120 km/h, load steps of 100, 115 and 125 % of the SW load, 8 and 12 out of 20 tires tested at each condition, respectively, fail before the test completion criteria of 50 hours.

Results for second test set:

All but one (P205/60R15, 160 kPa pressure) of H speed rated tires completed the test at 140 km/h (shown in two right bars for H tire in Figure 1).

Both the T tires tested at 140 km/h failed to complete 50-hour endurance test (shown in two right bars for T tire in Figure 1).

All the S speed rated tires failed to complete the 50-hour endurance test at 140 km/h speed (shown in two right bars for S tire in Figure 1)

Effect of Speed

The loading profile with steps at 100, 115, and 125 % of SW load was run at three test speeds of 100 km/h, 120 km/h, and 140km/h. All the H-rated tires endure the test without failure at 100 km/h (62 mph) and 120 (75 mph) km/h but at 140 km/h (90 mph) 1 out of 8 (12.5 %) tires tested failed to complete the 50-hour test duration.

For T-rated tires, all the tires endure the test without failure at 100 km/h (62 mph) but at 120 km/h (75 mph) and 140 km/h (90mph), 4 out of 10 (40 %) and 2 of 2 (100%) tires fail before completing the 50-hour test duration respectively.

Similarly for S-rated tires, all the tires endure the test without failure at the speed of 100 km/h (62 mph) but at 120 km/h (75 mph) and 140 km/h (90mph), 12 out of 20 (60 %) and 8 of 8 (100%) tires fail before completing the 50-hour test duration respectively.

Effect of Load

At a test speed equal to 120 km/h (75 mph) the tires were subjected to two profiles of load (SW load):

(1) 100 % SW load for first 8 hours
110 % SW load for next 10 hours
115 % SW load for next 32 hours

(2) 100 % SW load for first 8 hours
115 % SW load for next 10 hours
125 % SW load for next 32 hours

The load profile did not cause any variation of test results for H tires, as all the tires completed the test without failure.

For T-rated tires, 3 out of 10 (30 %) tires failed before completing the test when subjected to the load conditions described in (1) above. While 4 out of 10 (40 %) tires failed before completing the test when subjected to the load conditions described in (2) above.

Similarly, for S-rated tires, 8 out of 20 (40 %) tires failed before completing the test when subjected to load conditions described in (1) above. While 12 out of 20 (60 %) tires failed before completing the test when subjected to the load conditions described in (2) above.

Effect of Pressure

At 160 kPa Pressure:

One out of four (25%) H tires failed to complete the 50-hour endurance test at 140km/h.

One of one (100%) T tire failed to complete the 50-hour endurance test at 140km/h.

Four out of four (100%) S tires failed to complete the 50-hour endurance test at 140km/h.

At 180 kPa Pressure:

All the H tires completed the 50-hour endurance test.

All the T tires tested at 100km/h speed completed the 50-hour endurance test, while 7 out of 20 (35%) of the tires tested at 120km/h speed fail to complete the 50-hour endurance test.

All the S tires tested at 100km/h speed completed the 50-hour endurance test, while 20 out of 40 (50%) of the tires tested at 120km/h speed fail to complete the 50-hour endurance test.

At 200 kPa Pressure:

All the of H tires completed the 50-hour endurance test at 140km/h.

One of one (100%) of T tires failed to complete the 50-hour endurance test at 140km/h.

Four out of four (100%) of S tires failed to complete the 50-hour endurance test at 140km/h.

RMA TESTS

The Rubber Manufactures Association (RMA) conducted endurance tests on tires of size P235/75R15 with SR = S (180 km/h). RMA conducted all its tests on this tire size and controlled test speed, inflation pressure, and percent SW load application. Table 3 is the test matrix of endurance tests conducted by RMA. Twenty-eight tires were tested for each of the four conditions listed.

Table 3: Endurance Test Matrix of RMA Tire Tests

Tire Size	Speed Km/h (mph)	Pressure kPa (psi)	Load, Duration
P235/75R15 S	120 (75)	160 (23.2)	100 % SW load for first 8 hours 110 % SW load for next 8 hours 115 % SW load for next 8 hours (Increments of 5% SW load every 4 hours till failure)
	120 (75)	180 (26.1)	100 % SW load for first 8 hours 110 % SW load for next 8 hours 115 % SW load for next 8 hours (Increments of 5% SW load every 4 hours till failure)
	140 (87)	160 (23.2)	100 % SW load for first 8 hours 110 % SW load for next 8 hours 115 % SW load for next 8 hours (Increments of 5% SW load every 4 hours till failure)
	140 (87)	180 (26.1)	100 % SW load for first 8 hours 110 % SW load for next 8 hours 115 % SW load for next 8 hours (Increments of 5% SW load every 4 hours till failure)

The tests were conducted at two constant test speeds: 120 km/h (75 mph), and 140 km/h (87 mph). At each speed, tests were conducted at two inflation pressures: 160 kPa (23 psi), and 180 kPa (26 psi). Two tires each of 14 brands were tested.

The load application used is described as follows: 100 % of maximum SW load for 8 hours, 110 % of maximum SW load for next 8 hours, 115 % of maximum SW load for next 8 hours, and finally the load is incremented at 5% of the SW load every 4 hours until the tire fails. The percent load and the time-to-failure were recorded at tire failure. Table 4 provides a comparison between NHTSA and RMA endurance tests.

Table 4: Comparison Between NHTSA and RMA Endurance Tests

NHTSA	RMA
Speed Rating: Tests were conducted on tires with SR of (1) **S** 180 km/h (112 mph) (2) **T** 190 km/h (118 mph) (3) **H** 210 km/h (124 mph)	*Speed Rating:* Tested Tires only with SR of (1) **S** 180 km/h (112 mph)
Inflation Pressure: (1) 180 kPa (26 psi)	*Inflation Pressure:* (1) 160 kPa (23 psi) (2) 180 kPa (26 psi)
Percent SW load and Duration: Two levels of loading; (1) 100 % SW load for first 8 hours 110 % SW load for next 10 hours 115 % SW load for next 32 hours (2) 100 % SW load for first 8 hours 115 % SW load for next 10 hours 125 % SW load for next 32 hours	*Percent SW load and Duration:* One level of loading; (1) 100 % SW load for first 8 hours 110 % SW load for next 8 hours 115 % SW load for next 8 hours (Increments of 5% SW load every 4 hours until failure)
Test Speed: (1) 100 km/h (62 mph) (2) 120 km/h (75 mph)	*Test Speed:* (1) 120 km/h (75 mph) (2) 140 km/h (87 mph)
Test completion criteria: Tire failure or complete 50 hours of testing, whichever occurs first.	*Test completion criteria:* Tire failure.
Number of tires tested: 120 tires	*Number of tires tested:* 112 tires

RMA TEST RESULTS

Figure 2 is a comparison of the mean time-to-failure at two test-inflation pressures 160 kPa (23 psi) and 180 kPa (26 psi). The bar at left for each pressure is the mean time-to-failure at a test speed 120 km/h (75 mph) while the bars at right represents time-to-failure at a test speed of 140 km/h (62 mph).

Figure 2: Comparison of time at failure for Endurance test RMA Data

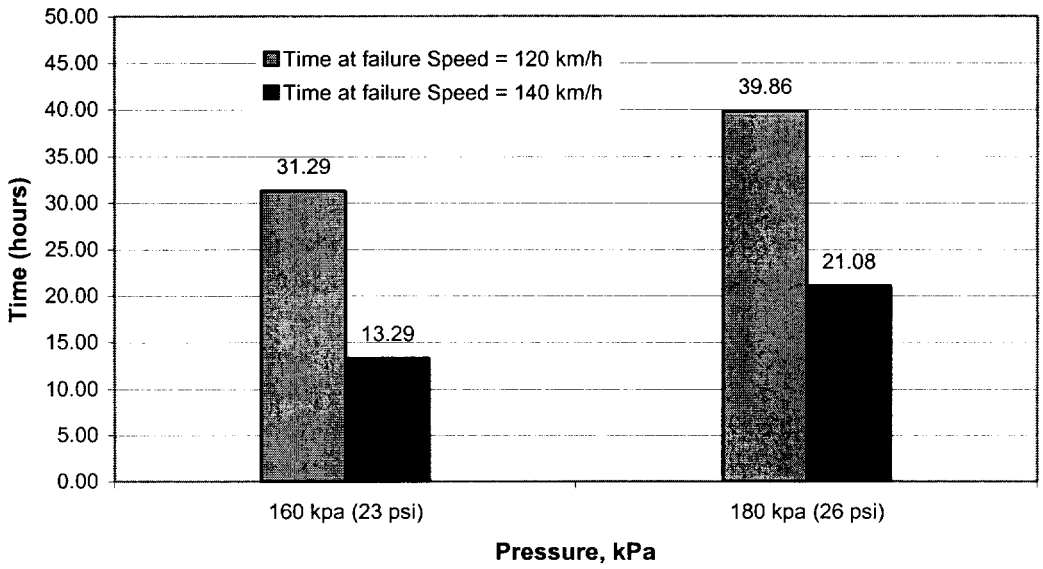
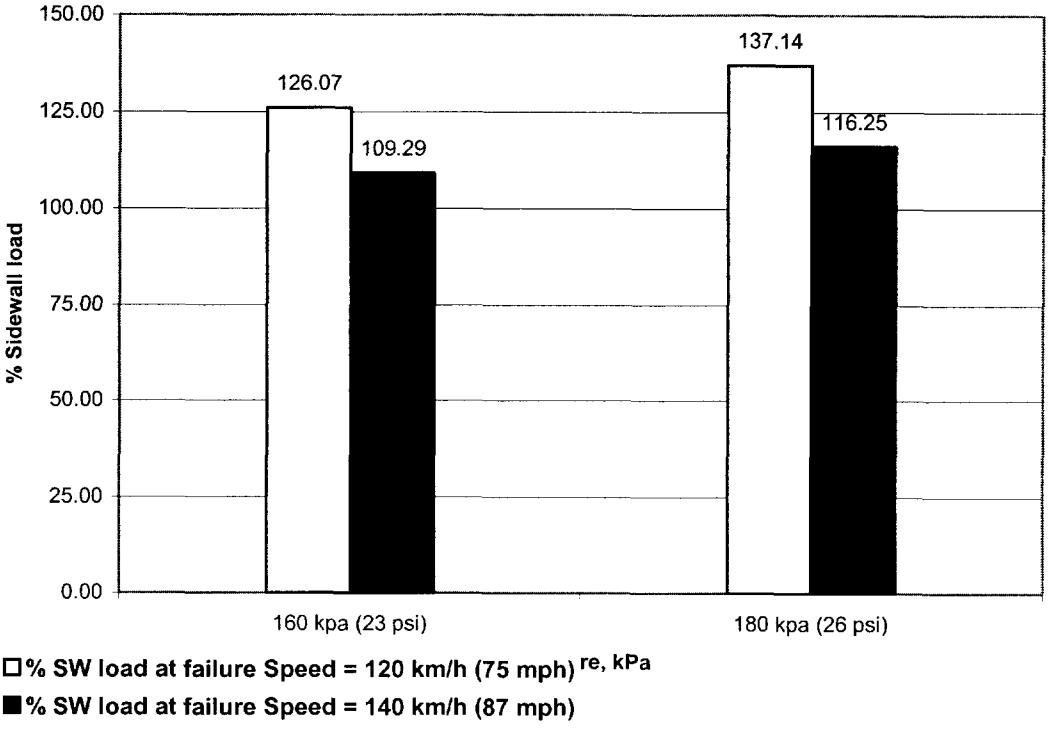


Figure 3 is a comparison of the mean percent SW load at failure, at two test-inflation pressures 160 kPa (23 psi) and 180 kPa (26 psi). The bar at left for each pressure is the mean percent SW load at a test speed 120 km/h (75 mph) while the bars at right represents the mean percent SW load at a test speed of 140 km/h (62 mph).

Figure 3: Comparison of percent sidewall load at failure for Endurance test RMA Data



Effect of Pressure

At 120 km/h (62 mph), the mean time-to-failure was 31.3 hours at 160 kPa (23 psi) while it was 39.9 hours at 180 kPa (26 psi). An increase in pressure by 20 kPa at a constant speed of 120 km/h resulted in an increase in mean time-to-failure by 8.6 hours. This change in pressure also resulted in an increase in percent SW load applied from 126 % to 137 %, i.e. a change of 11 % of SW load.

Similarly at 140 km/h (75 mph) the mean time-to-failure was 13.3 hours at 160 kPa (23 psi) while it was 21.1 hours at 180 kPa (26 psi). An increase in pressure by 20 kPa at a constant speed of 120 km/h resulted in an increase in mean time-to-failure by 7.8 hours. This change in pressure also resulted in an increase in percent SW load applied from 109 % to 116 %, i.e. a change of 7 % of SW load.

Effect of Speed

The effect of test speed on mean time-to-failure was found by varying the test speed from 120 km/h to 140 km/h and holding pressure constant at 160 kPa. The mean

time-to-failure decreased to 13.3 hours from 31.3 hours when the speed was increased to 140 km/h from 120 km/h, a decrease of 18 hours in mean time-to-failure. The above increase of test speed from 120 to 140 km/h also resulted in as decrease of percent SW load from 126 % to 109 %, i.e., a decrease of 16 % in SW load.

Similarly, the effect of test speed was found for a constant inflation pressure of 180 kPa. The mean time-to-failure decreased to 21.1 hours from 39.9 hours when the speed was increased to 140 km/h from 120 km/h, a decrease of almost 19 hours in mean time-to-failure. The above increase of test speed from 120 km/h to 140 km/h also resulted in an increase of percent SW load from 137 % to 116 %, i.e., an increase of 21 % in SW load.

ANALYSIS OF DATA

Impact of Proposed Test

One important question that can be addressed with these data is: "How many tires would fail the endurance test in the NPRM?"

The proposed endurance test is run at a speed of 120km/h with a cold inflation pressure of 180 kPa (26 psi) and loading conditions of 90% maximum load for 8 hours, followed by 100% of maximum load for 10 hours, followed by 110 % maximum load for 22 hours.

To be able to use the available data to address this question, it is necessary to find a common measure that can be associated with all of the test conditions. The parameter that has been selected for this analysis is: Time at, or above, 110% maximum load (FT ($\geq$110 %)). This measure is consistent with the theory of fatigue failures, or endurance limit, of materials. This type of failure has been described as follows:

> For many materials, long experience has proved that when the stress is below a certain value called the fatigue or endurance limit, the part will last indefinitely so far as ill effects from the stress are concerned. However, for slightly greater values of the stress, failure can be expected after a certain number of repetitions of the stress cycle. Failure (is) brought about by a tiny crack, which

> started at a stress concentration or at a flaw in the material at a highly stressed point. The crack itself serves as a stress concentration, and grows continually larger until the failure of the part occurs. [2]

It appears from the available data that a load of 110 % is needed to exceed the stress that tires can accommodate indefinitely at inflation pressures of 180 kPa or greater. For example, none of the tires tested at inflation pressures of 180 kPa or greater failed at load levels less than 110 %. Thus, measuring the time-to-failure starting at the point that the tire experiences 110 % or greater load is an appropriate measure of endurance performance.

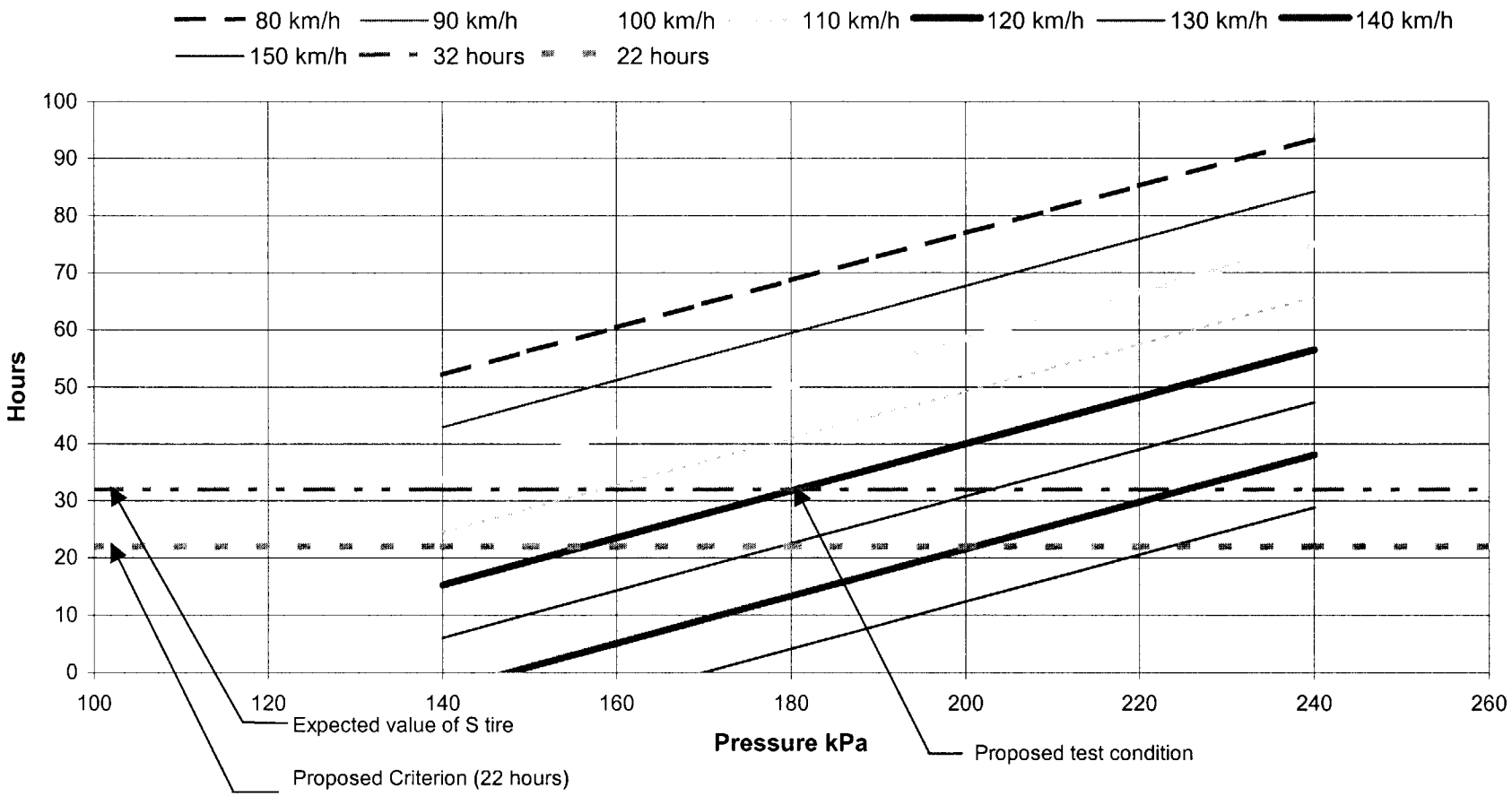
The first step in the analysis is to establish a relationship between FT ($\geq$110 %), inflation pressure, and test speed. This relationship for tires with an S speed rating can be derived from the RMA data. The results are shown in Figure 4.

Figure 4 describes the predicted number of hours (ordinate) an S-rated tire would endure when subjected to 110 %, or greater, of the maximum SW load at a specified speed with respect to inflation pressure (abscissa). The dotted line at the bottom of the plot is the number of hours the tire should endure at 110% SW load in order to complete the endurance test described in section S6.3.1.2.3 of the proposed rulemaking. For S-rated tires at 120 km/h and 180 kPa inflation pressure, the mean time-to-failure is 32 hours. This is 10 hours longer than the proposed criterion of 22 hours.

---

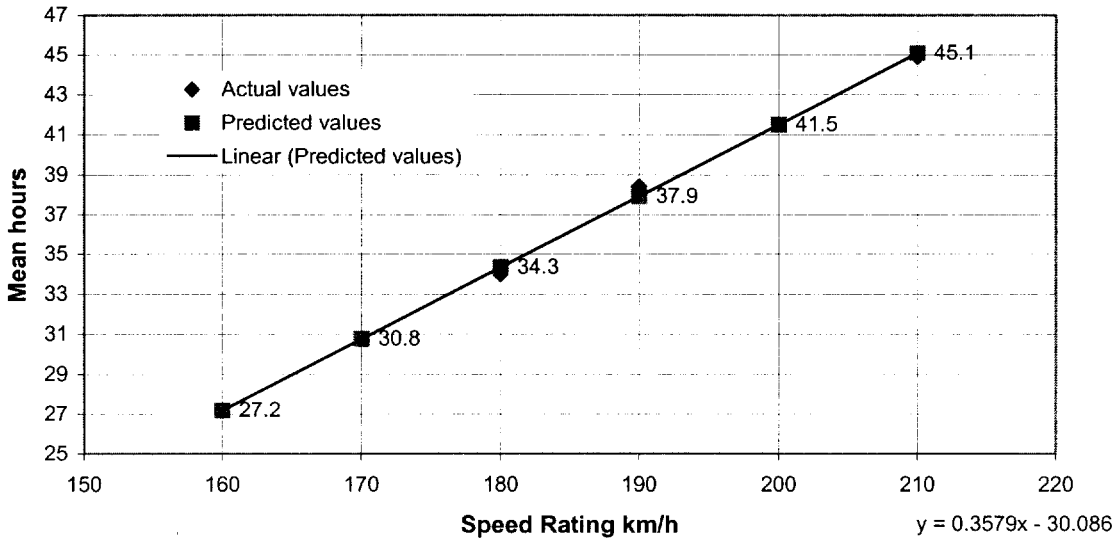
[2]M. F. Spotts, *Design of Machine Elements*, Prentice-Hall, 1961

Figure 4: Mean time-to-failure at load equal to or greater than 110 % of sidewall for S tires, RMA data



The second step is to determine the relationship for failure rates between tires with different speed ratings. This can be obtained from the NHTSA data. This is shown graphically in Figure 5 for the results at the proposed speed and pressure.

Figure 5: Predicted mean hours at 110 % or greater SW load, to failure or test completion, NHTSA data, 180 kPa pressure and 120 km/h speed



The NHTSA test data at 120 km/h speed and 180 kPa inflation pressure with loading as indicated in the center bar of Figure 1 for the three types of tires (SR of H, T, & S) are used to analyze the effect of SR.

In order to make the NHTSA data more representative of the tire's performance (endurance), interpolations were made to the test data that were stopped at end of 50 hours. For the NHTSA tests that had similar test profiles to the RMA tests, the distribution of data at 50 hours in NHTSA data, were replaced by the distribution of FT ($\geq$110 %) at 50 hours or more in RMA data.

All the H-rated tires completed the NHTSA test of 50 hours or more, which indicates that all the H tires completed at least 42 hours or more at loads 110 % SW load, or greater. The mean FT ($\geq$110 %) for H-rated tires was calculated by taking the mean of the distribution of RMA data that replaced the NHTSA data where the test is

terminated at the end of 42 hours. This mean FT (≥110 %) for RMA data is equal to 45 hours. Similarly, the mean FT (≥110 %) for T and S tires are 37.9 and 34.3 hours. The regression expression for these data is also shown in Figure 5. Using this regression expression, values were predicted for mean FT (≥110 %), which are also plotted in Figure 5. At speed rating of 160 (Q), 170 (R), and 200 (U), the predicted values for FT (≥110%) are 27.2, 30.8, and 41.5 hours respectively.

The difference between mean FT (≥110 %) for the loading profile with steps "100, 110, 115 % " SW load and the profile with steps "100, 115, 125 %" SW load at 120 km/h is 2.8 hours for T-rated tires while it is 1.65 hours for S-rated tires. This effect of the loading profile is not as significant as tire type and test speed shown in Figure 1 and are not included in the above regression analysis.

The third step considers the distribution of failure times. The results above are for the mean values of FT (≥110 %). However, as seen in Figure 1, there is a large variance between tires, and some tires fail in as little as 8 hours at 110 %, or greater, SW load.

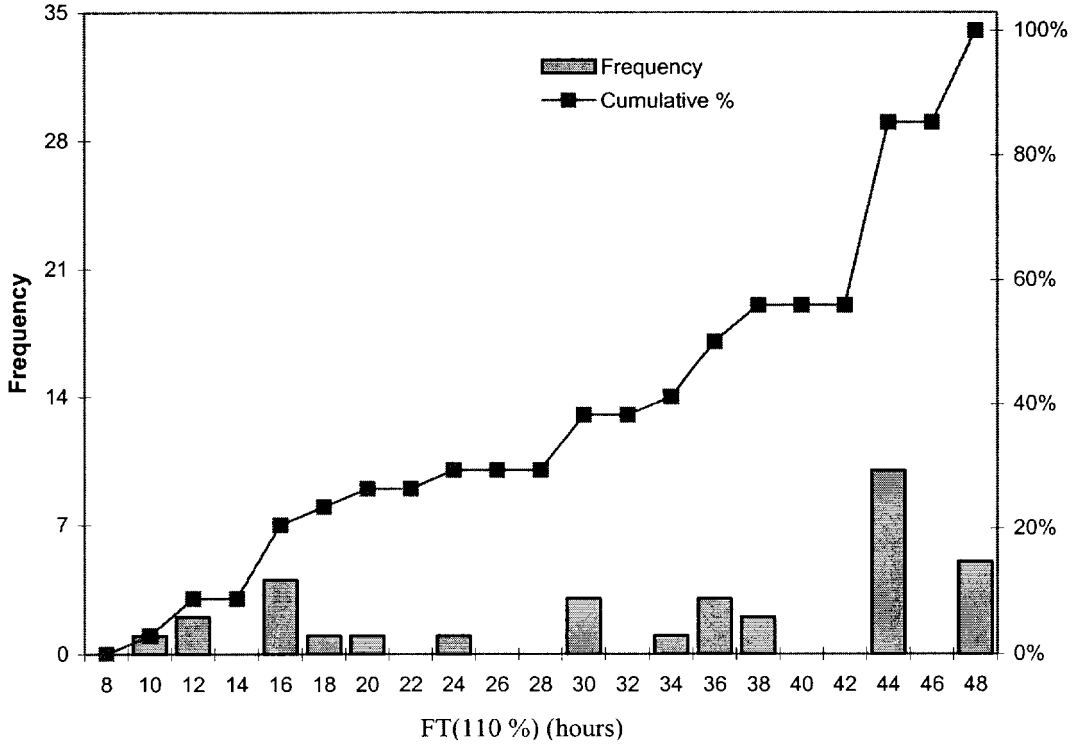
The RMA data for S-rated tires[3] were combined with the NHTSA data for S tires[4]. The FT (≥110 %) was taken as the variable for distribution. NHTSA data which had tests stopped at 42 hours were replaced by the distribution of RMA data which had FT (≥110 %) of 42 hours, or greater, to make the consolidated data more representative of true performance.

Figure 6 is the distribution FT (≥110 %) at failure for S-rated tires; the mean time at failure for S-rated tires at 110 % SW load from Figure 5 is 34 hours. In the Agency's proposed endurance test, the tire would be tested for 22 hours at 110% SW load, 180 kPa and 120 km/h. An estimate of distribution of FT (≥110 %) relative to the 22-hour criterion for tires with speed-rating other than S can be obtained by overlaying the

[3] 180 kPa, 100 % SW load for the first 8 hours, 110 % SW load for next 8 hours, 115 % SW load for next 8 hours (Increments of 5% SW load every 4 hours until failure), test speed of 120 km/h.
[4] 180 kPa, 100 % SW load for the first 8 hours, 110 % SW load for next 10 hours, 115 % SW load for last 32 hours, test speed of 120 km/h.

distribution of Figure 6 on the mean values shown in the Figure 5 for each level of speed rating.

Figure 6: Distribution of hours to failure at 110 % or greater SW load, 180 kpa pressure, and 120 km/h speed for "S" SR tires NHTSA and RMA data combined



The procedure used to predict the percent less than 22 hours of time-to-failure is described in Appendix 1 for Q-rated (160 km/h) tires. Similarly, estimate of failure rate for R (170 km/h), S (180 km/h), T (190 km/h), U (200 km/h), and H (210 km/h) tires are shown in Table 5.

Table 5: Percent of Tires That Would Not Complete 22 Hours At 110% SW Load

Speed Rating	Percent Failure
Q	30
R	30
S	26
T	24
U	9
H	3

Note: In the above interpolation the effect of variation of loading profile in the various tests is not taken into account.

CONCLUSION

Based on the available data and analysis it appears that the following percentages of tires will not complete the proposed endurance tests: about 30 % of tires with a speed rating of Q and R, about 25 % of S and T, about 9 % of U and about 3 % of H.

APPENDIX

This procedure assumes that the distribution of time-to-failure is same for all speed rating.

As an example of the procedure, the following steps are taken to estimate the distribution of FT (≥110 %) for Q rated (160 km/h) tires:

(1) The mean time-to-failure is determined for Q tire from Figure 5, and is equal to 27.2 hours.

(2) Figure A1 is a distribution of FT (≥110 %), relative to the mean FT (≥110 %) as derived from Figure 6.

(3) The distribution of FT (≥110 %) for Q-rated tires is obtained by adding the mean FT (≥110 %) of Q-rated tire to the distribution in Figure A1 to get the distribution shown in Figure A2.

Figure A1: Distribution of mean hours at 110 %, or greater, SW load, 180 kpa pressure and 120 km/h speed

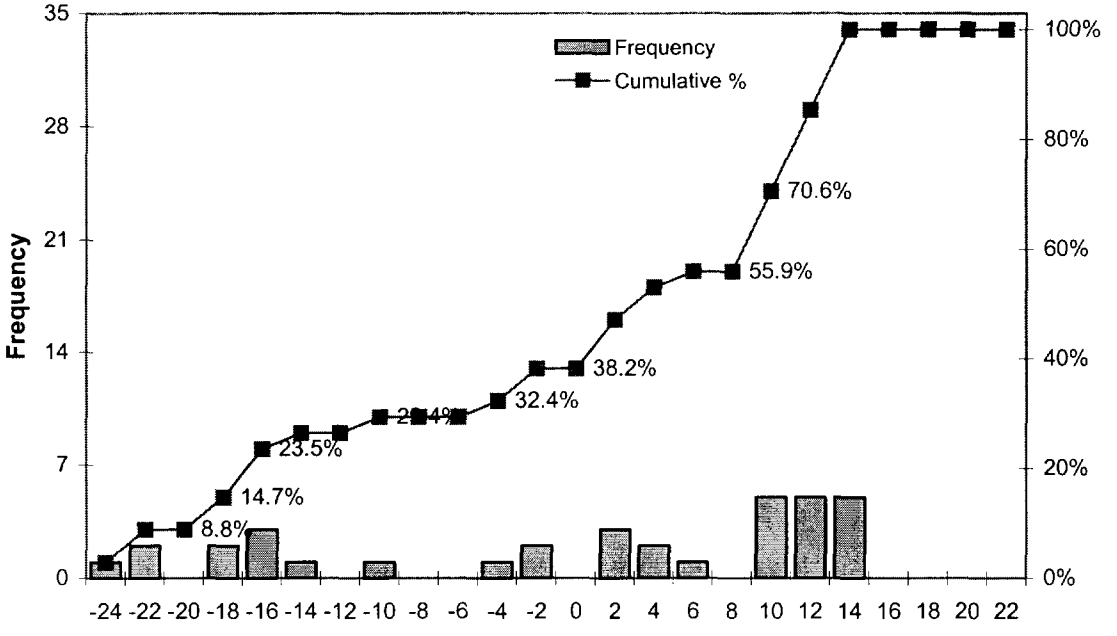
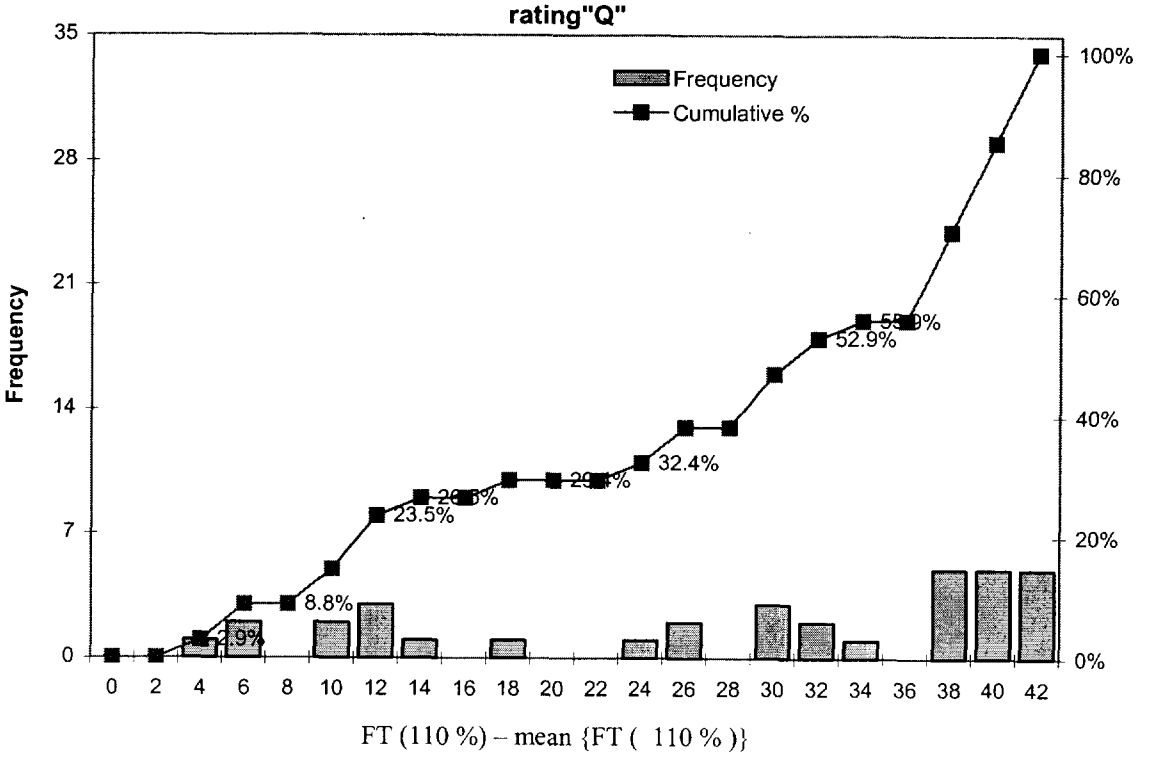


Figure A2: Distribution of hours at time to faliure at load equal to 110% or greater SW load, 180 kpa pressure and 120 km/h speed for with speed rating"Q"



Considering the proposed criteria for endurance test, all the tires below 22 hours in Figure A2 (29.4%) fail to complete the test duration of 22 hours.